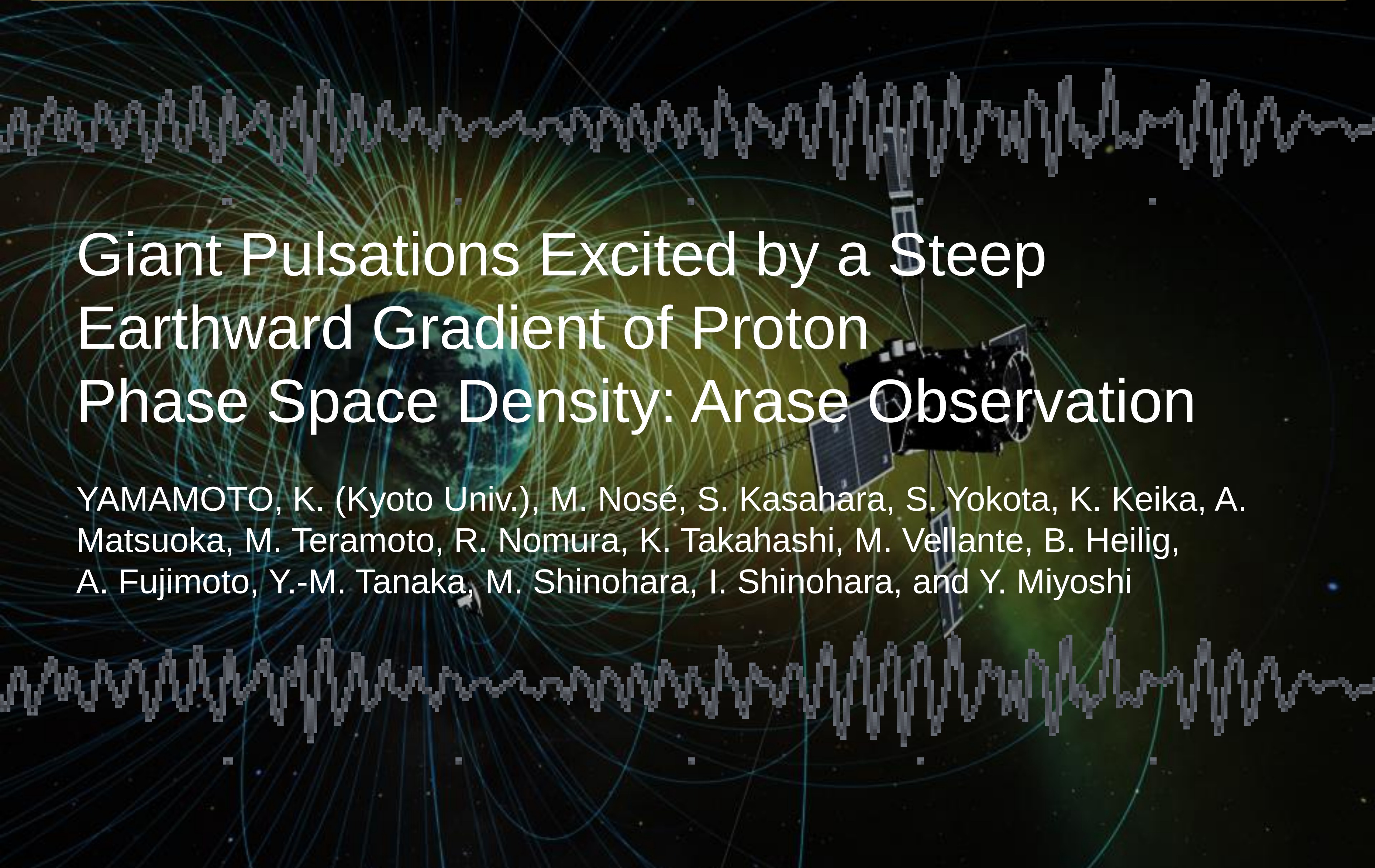
平成30年度極域・中緯度SuperDARN研究集会　16th October 2018



Giant Pulsations Excited by a Steep Earthward Gradient of Proton Phase Space Density: Arase Observation

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Introduction and Motivation

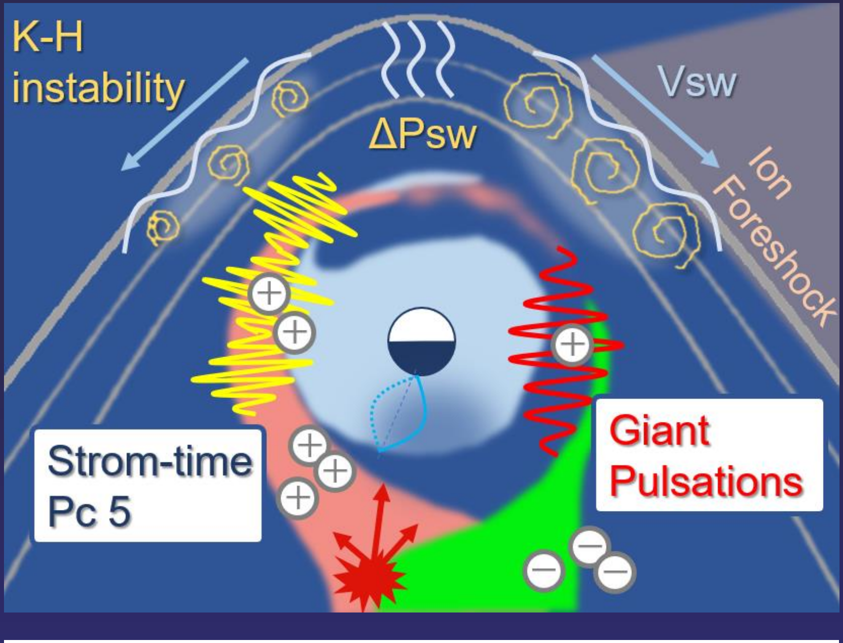
Internal Energy Source for ULF Waves

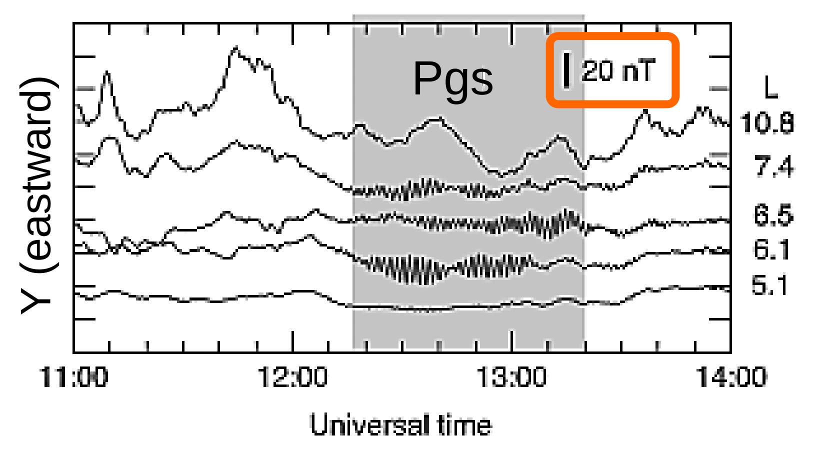
- high-*m* waves
  $|m| \sim 100$, $m < 0$
  (westward)
- dusk side (spacecraft)
- drift-bounce resonance

m : azimuthal wave number

Giant Pulsations (Pgs)

- dawn side (ground stations)
- large wave amplitudes
- moderate *m* number
  $|m| \sim 30 – 40$, $m < 0$





Takahashi et al. (2011)

Remained Questions about Giant Pulsations

- excitation mechanism
  - ⋆ drift-bounce resonance (with ~10keV protons) or drift resonance (with ~100 keV protons)?
  - ⋆ bump-on-tail structure?

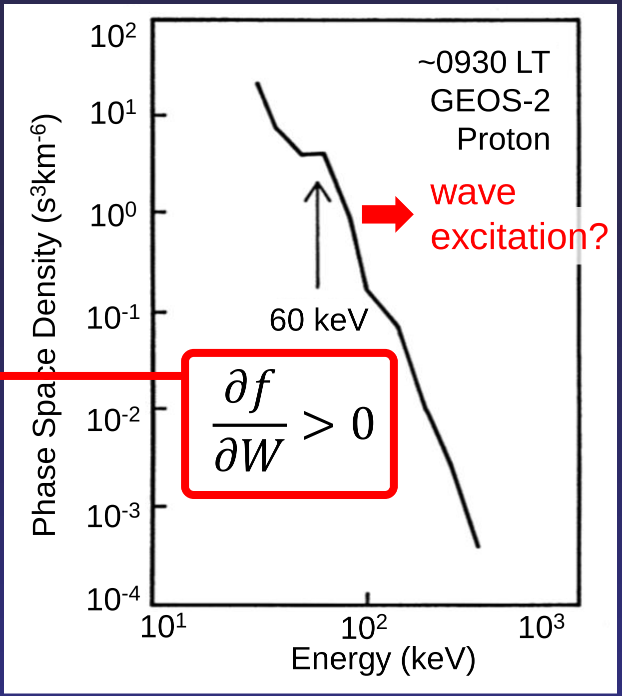
$$\frac{df}{dW} = \left(\frac{\partial f}{\partial W}\right)_{\mu,L} + \frac{mL^2}{qR_e^2\omega B_{eq}}\left(\frac{\partial f}{\partial L}\right)_{\mu,W} > 0$$ (destabilization)

energy gradient radial gradient

f: phase space density, W: energy, *μ*: magnetic moment, *ω*: wave frequency, *m*: *m* number

Southwood & Kivelson, (1969; 1981)

Glassmeier et al. (1999)



drift resonance (fundamental)	drift-bounce resonance (2nd harmonic)
・Takahashi et al. (1991, 2011, 2018)	・Chisham and Orr (1991)
・Thompson and Kivelson (2001)	・Ozeke and Mann (2001)
・Motoba et al. (2015)	・Wright et al. (2001)

Experiments and Data

Experiments

- We analyzed the data of the Arase satellite.
- We checked following three criteria to confirm the wave-particle interaction:

(C1) Is the flux (also) oscillating?

(C2) Is the resonance condition satisfied?

$$\omega - \underbrace{m}_{\text{ground stations}}\omega_d = N\omega_b$$

ω_d: drift frequency,
ω_b: bounce frequency,
N: integer

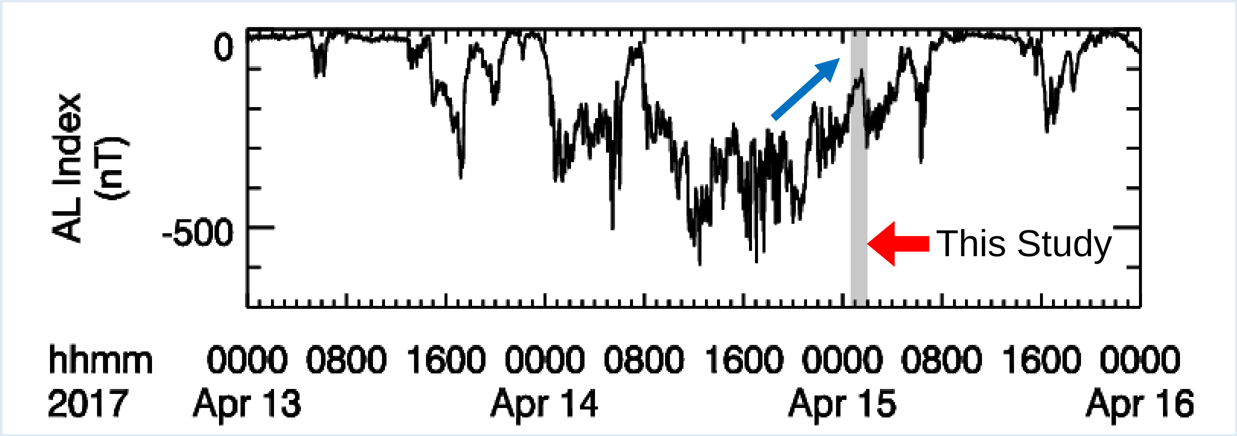
(C3) is d*f*/d*W* positive (destabilization)?

$$\frac{df}{dW} = \underbrace{\left(\frac{\partial f}{\partial W}\right)_{\mu,L}^{\text{Arase}}}_{\text{energy gradient}} + \frac{mL^2}{qR_e^2\omega B_{eq}}\underbrace{\left(\frac{\partial f}{\partial L}\right)_{\mu,W}^{\text{Arase}}}_{\text{radial gradient}}$$

Data

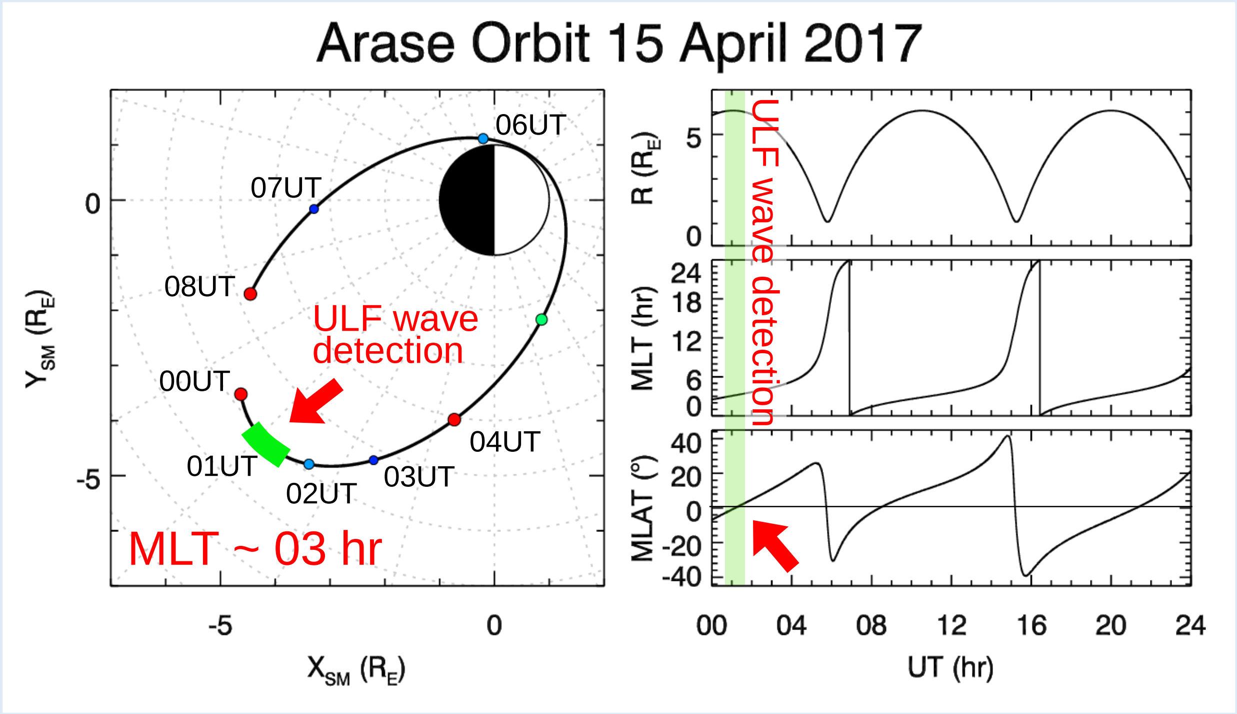
- MGF (magnetic field)
  8-sec values
- MEP-i (energetic ions)
  8-sec values of protons
  energy range: 5.1 – 109.6 keV
- ground magnetometers (EMMA)
  1-sec values

Observation: Orbit of the Arase Satellite



Geomagnetic Condition

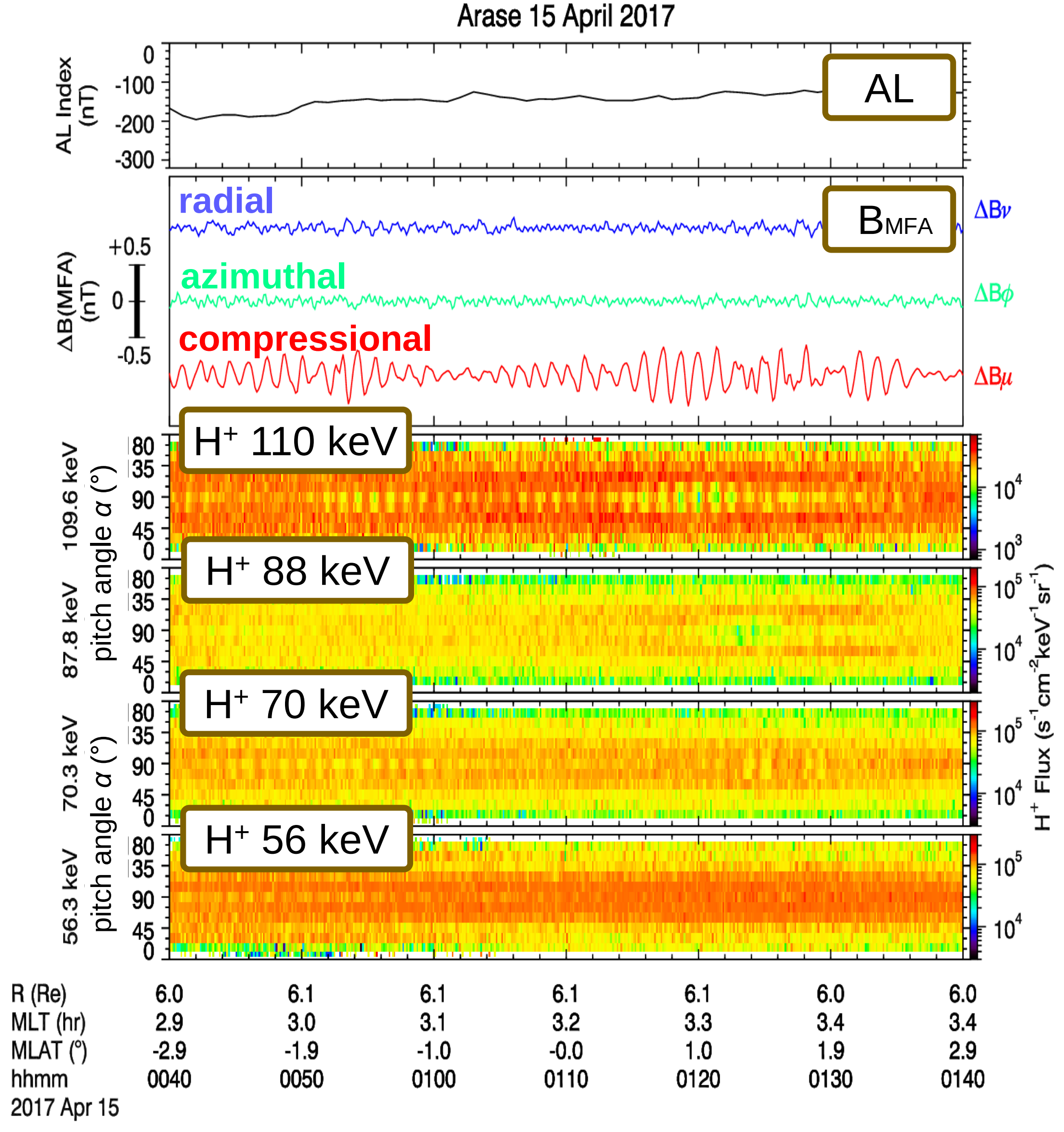
- substorms on April 14
- recovery phase

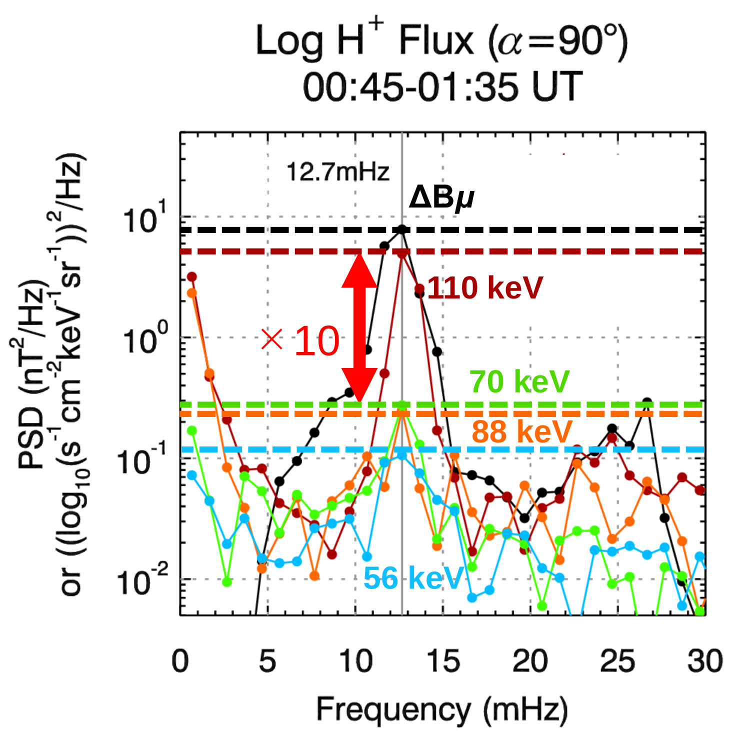


Location of the Spacecraft

- detection of ULF wave during 0040 – 0140 UT
- dawn side
- magnetic equator

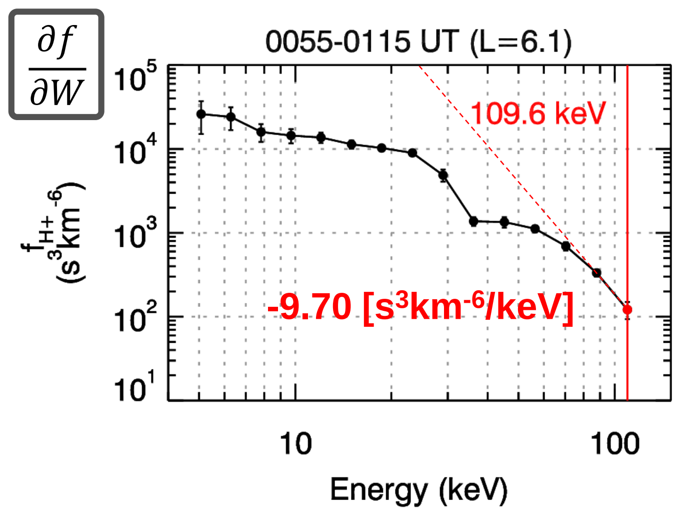
Observation: Overview of MGF and MEP-i Data



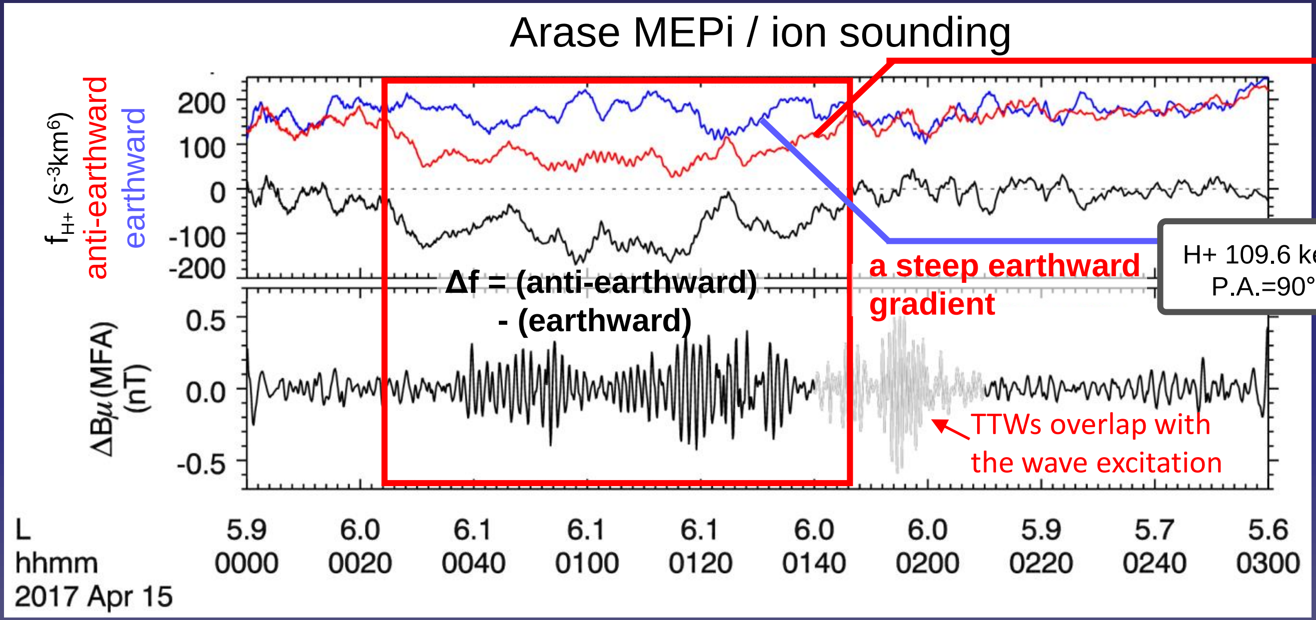


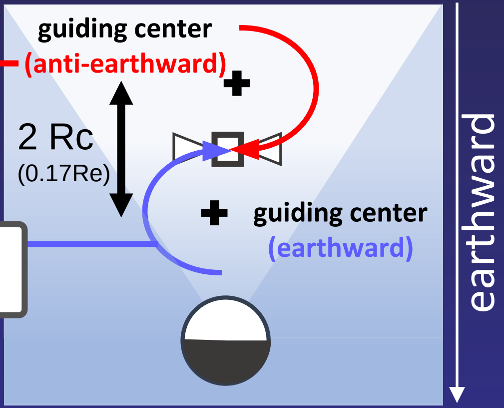
- compressional Pc4 waves (~13 mHz)
- H+ flux oscillations at >50 keV (largest at 109.6 keV) →(C1)

Observation: Distribution of Phase Space Density



- The energy gradient of proton phase space density was obtained from the energy spectrum.
- The radial gradient of proton phase space density was estimated by using the ion sounding technique. →(C3)



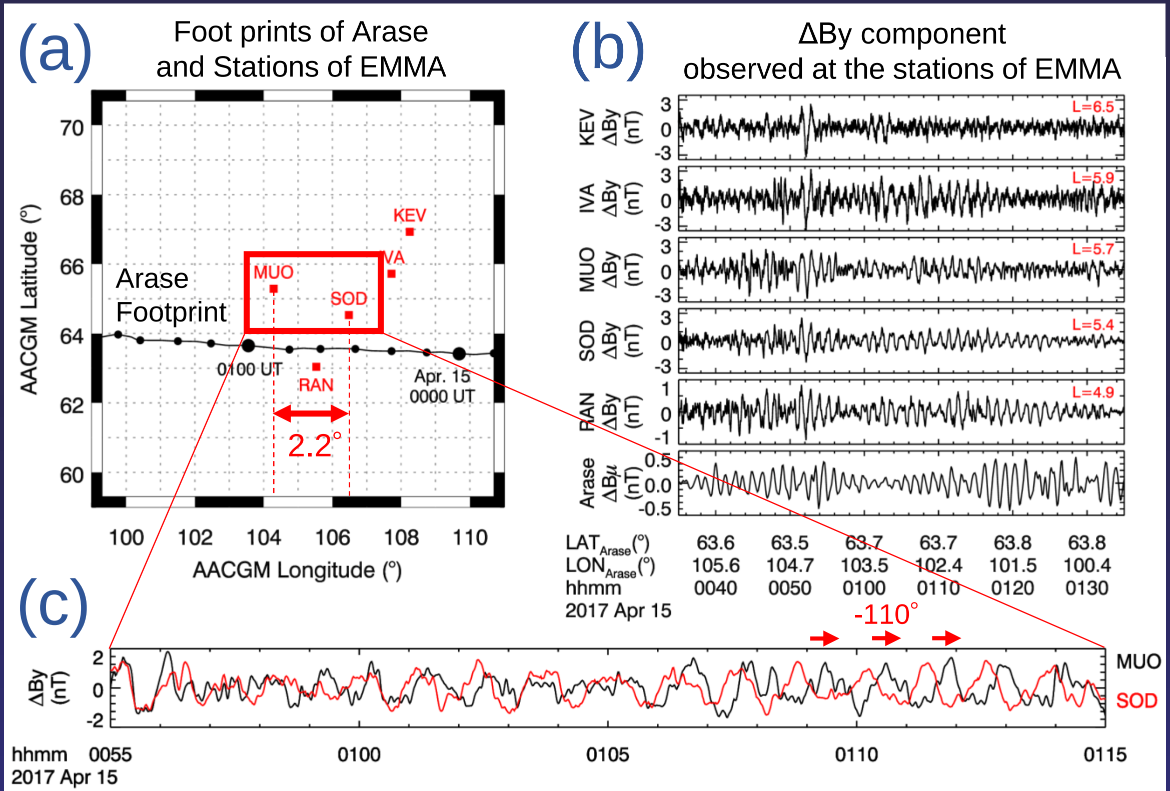


Rc: a gyro-radius of protons

$$\frac{\partial f}{\partial L} \sim \frac{\Delta f}{2Rc} \quad \text{(for 0055-0115 UT)}$$

$$= -748\ [\mathrm{s}^3\mathrm{km}^{-6}/R_E]$$

Observation: Geomagnetic field at Ground Stations


(a) Foot prints of Arase and Stations of EMMA

(b) ΔBy component observed at the stations of EMMA

(c)

- Estimation of the *m* number from cross phase

$$m = \frac{\theta_{MUO} - \theta_{SOD}}{|lon_{MUO} - lon_{SOD}|}$$

m: *m* number,
θ: phase of the waves observed at MUO or SOD,
lon: AACGM longitude at MUO or SOD

To confirm the resonance condition (C2), we estimated the *m* number.

We used longitudinally separated stations (SOD and MUO) of EMMA.

The phase of SOD leads that of MUO by -108° to -113°.

➡ *m* = -49 to -52
(westward propagation)

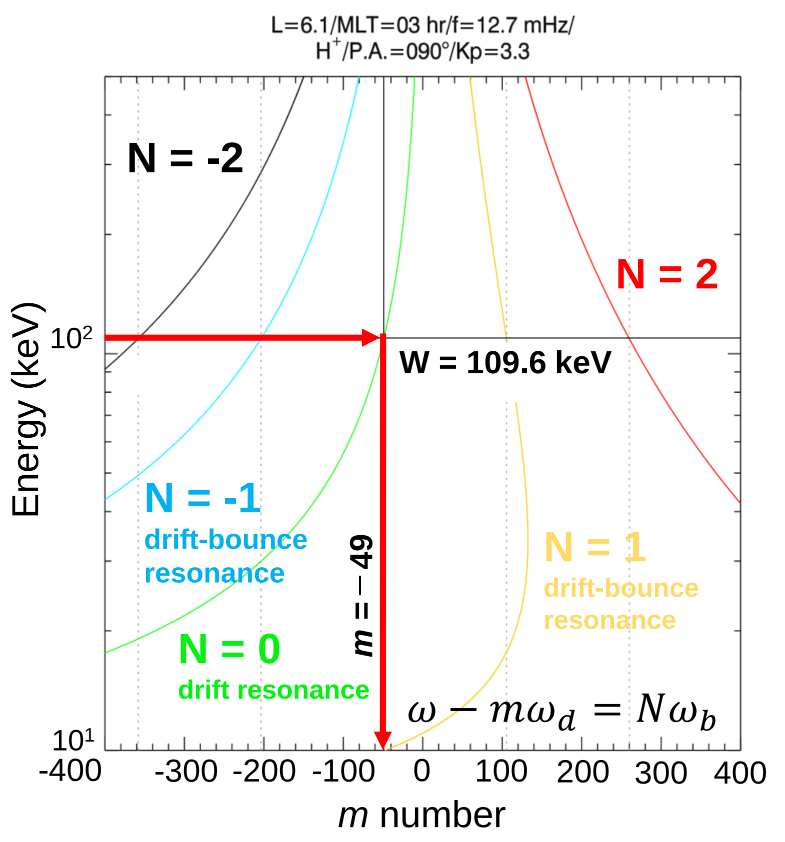
Discussion: Instability Analysis

Check on the Resonance Condition (C2)

- The resonance particles are assumed to be protons at *W* = 109.6 keV and *α* = 90°.

➡ *m* = -49 (*N* = 0, <u>drift resonance</u>)

close to the estimation from observation!



Stabilization or Destabilization (C3)

- $df/dW = \partial f/\partial W + m/(qR_E^2 \omega B_{eq}) \times \underline{\partial f/\partial L}$ a steep earthward gradient

  $= -9.70 + \underline{(-1.73\times10^{-2})\times(-7.48\times10^{2})} = 3.22\ [\mathrm{s^3km^{-6}/keV}] > 0$

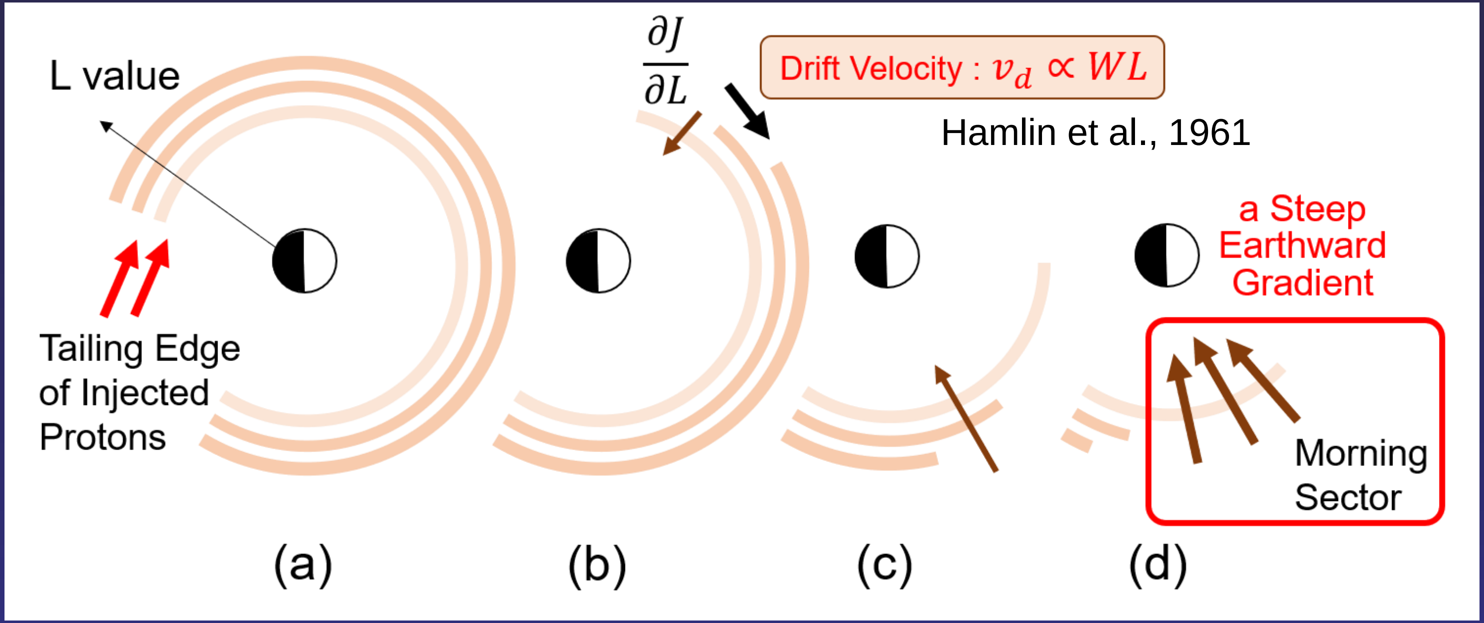
  wave excitation

- The steep earthward gradient excites the waves.

Discussion: Cause of the Steep Earthward Gradient

What causes the steep earthward gradient?

- trailing edge of injected particles



(a) Injection may be interrupted and the trailing edge of injected protons is formed.

(b) The trailing edge at larger *L* propagates faster than that at smaller *L*.

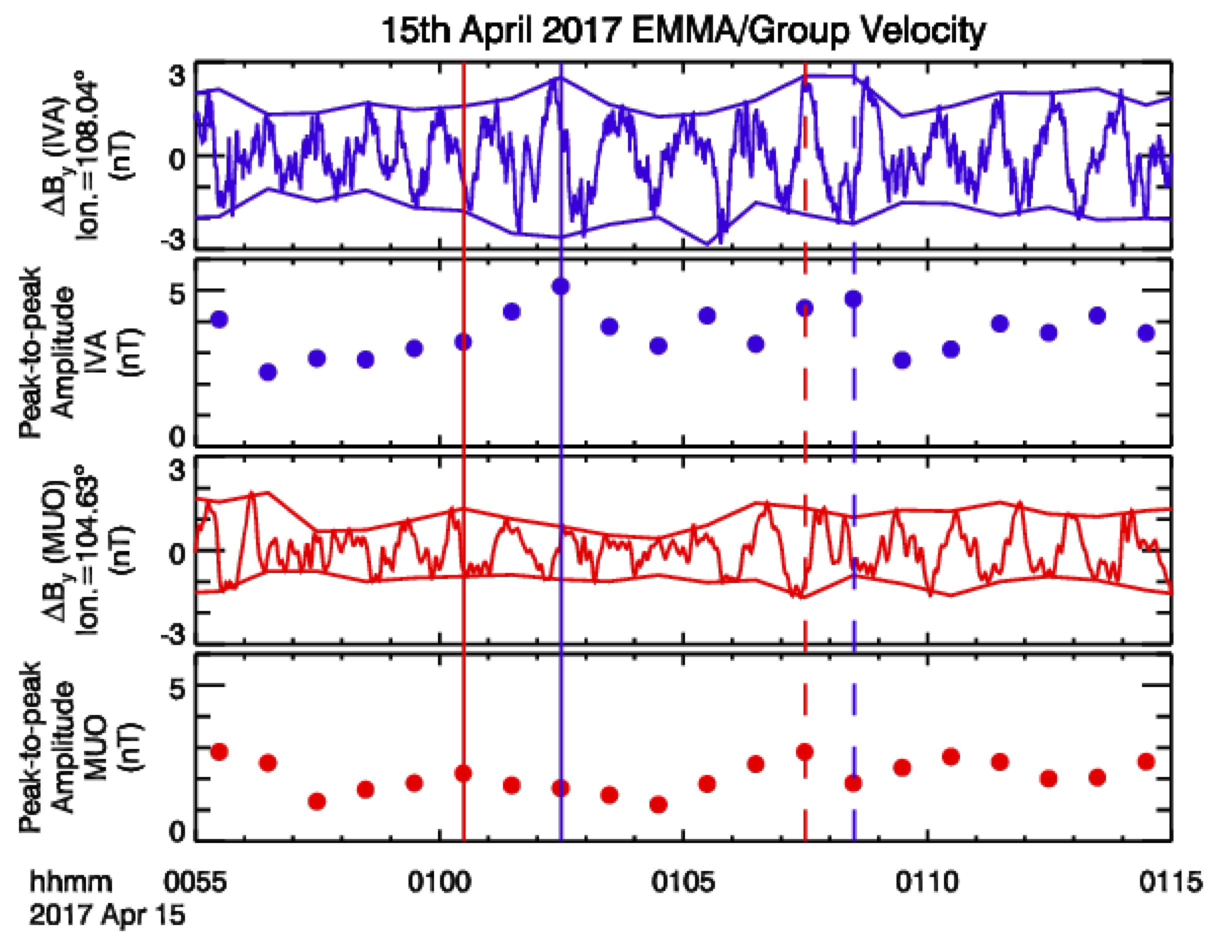
(c-d) The outside protons have dropped out and a steep earthward gradient is created in the morning sector.

Discussion: Group Velocity of the Waves

Is the energy source moving?

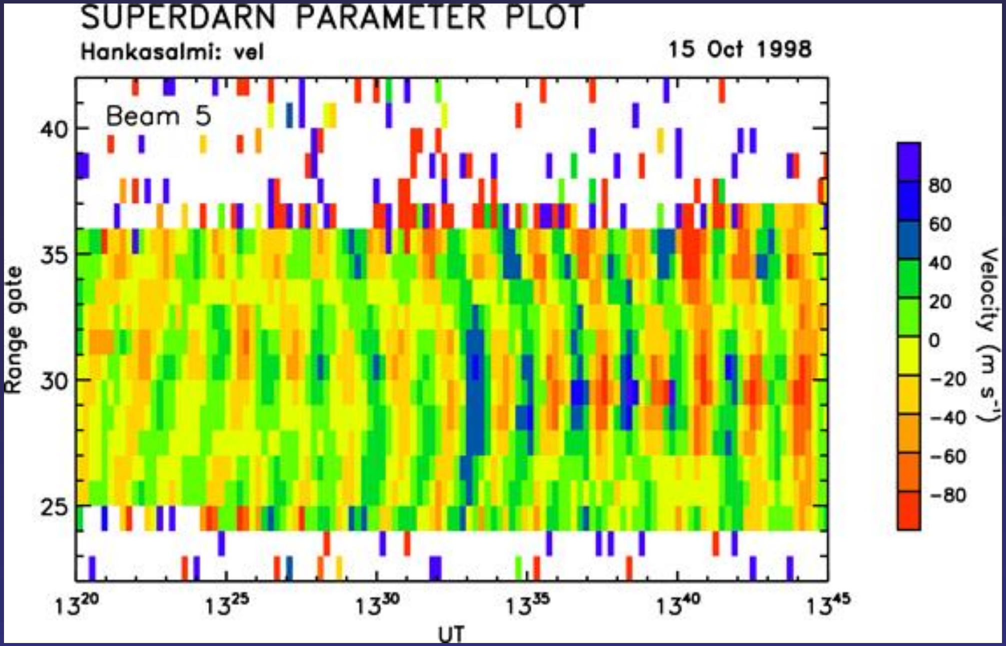
The wave packet observed at IVA led that observed at MUO by ~90 sec, which corresponds to an angular frequency of -6.6 × 10^{-4} [rad/s].

The drift angular velocity of 110 keV protons is -1.6 × 10^{-3} [rad/s] (Comparable to the group velocity?)



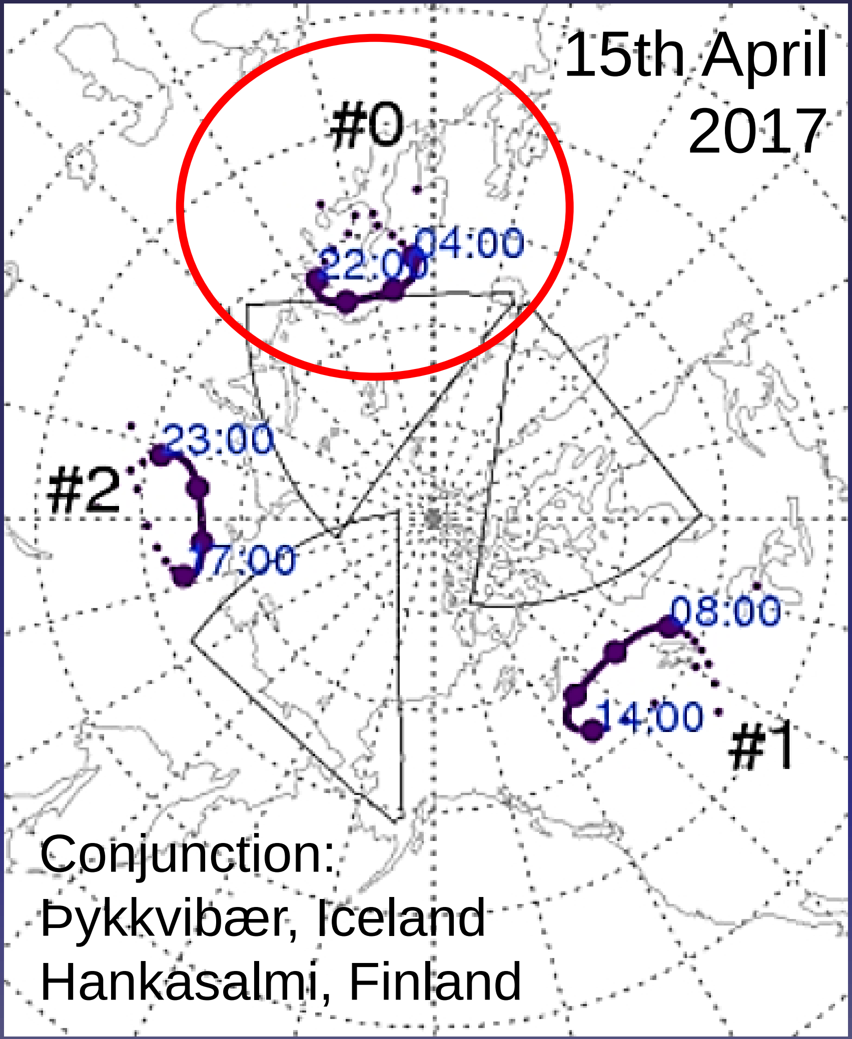
Discussion: Potential of SuperDARN Data

What we expect if the energy source is moving



Yeoman et al. (2012)

From the SuperDARN observation, Yeoman et al. (2012) suggested that the curved phase fronts of the line-of-sight velocity result from a moving wave energy source.



15th April 2017

Conjunction:
Þykkvibær, Iceland
Hankasalmi, Finland

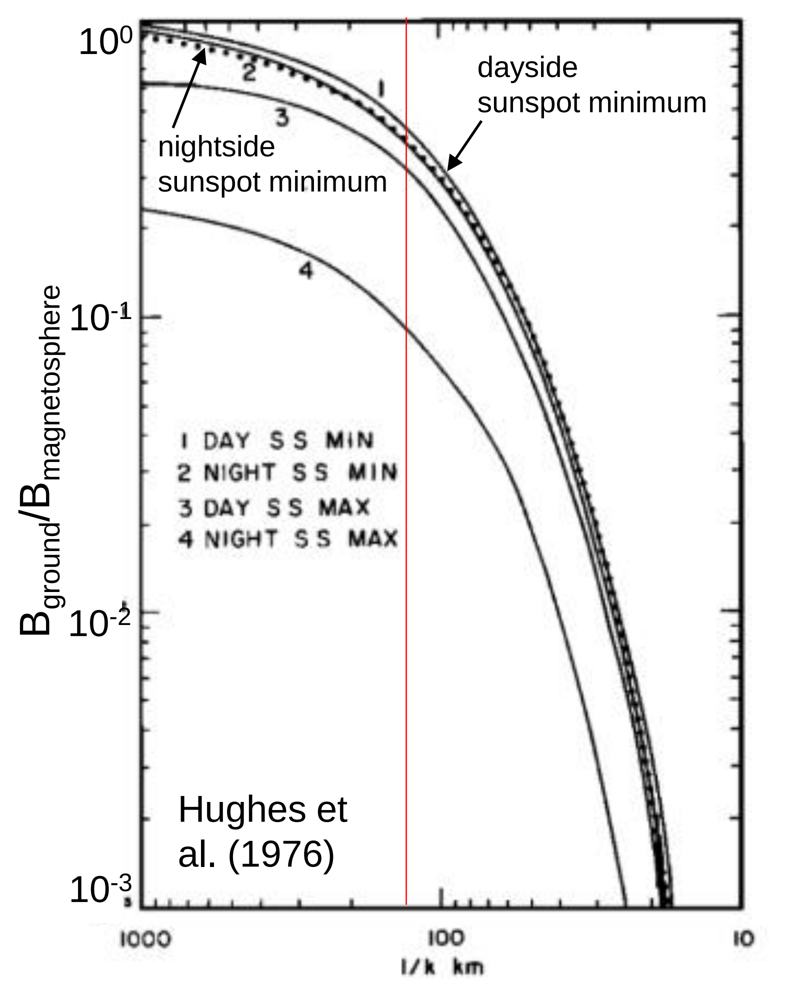
https://ergsc.isee.nagoya-u.ac.jp/cef/orbit_ergsd.cgi

Conclusions

- On April 15, 2017, the Arase satellite detected a compressional magnetic field oscillation in the Pc4 band that is related to a giant pulsation observed on the ground.
- We found evidence that the waves were in drift resonance with ~110 keV protons.
- In previous studies, a bump-on-tail distribution was considered as an energy source of Pgs; however, the Pc4 waves examined in this study were excited by a steep earthward gradient of proton phase space density. This is a new founding because the previous studies focused on only a bump-on-tail structure.
- We suggest that the steep earthward gradient are related to substorm recovery phase.

Backup Slide

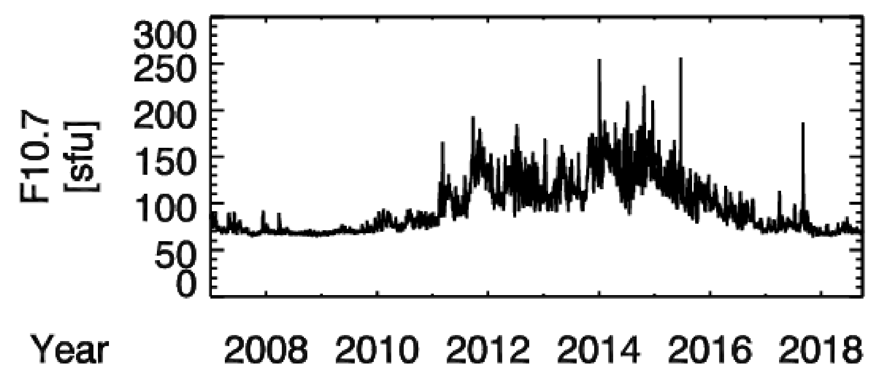
- Ionospheric Screening Effect



Hughes et al. (1976)

Assuming |*m*| ~ 50, $k^{-1} = \lambda/2\pi = 2\pi \times Re / m / 2\pi = Re / m \sim 130$.

Arase is operating during the declining phase or solar minimum.



Backup Slide

- Yeoman et al. (2012)